An Experimental Analysis of Air-Steam Gasification in A Fluidized Bed

1. V.Chokkalingam, 2. S.Rajendran, 3.P.Mohanraj, 4. S.Jeyan

1,2, Professor, Department of Mechanical Engineering, Jaya Engineering College Chennai 602024,INDIA.

3, Assistant Professor, Department of Aeronautical Engineering, Jaya Engineering College Chennai 602024

4. Assistant Professor, Department of Mechanical Engineering, Jaya Engineering College Chennai, INDIA

Email: lingamviswakethu@gmail.com

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Abstract

This study applies a self-heated Fluidized bed gasifier as the reactor and uses char as the catalyst to study the characteristics of hydrogen production from biomass gasification. Air and oxygen/steam are utilized as the gasifying agents. The maximum lower heating value of fuel gas reaches 11.11 MJ/N m^3 for biomass oxygen/steam gasification. Over the ranges of operating conditions examined, the maximum hydrogen yield reaches 45.16 g H_2/kg biomass. For biomass oxygen/steam gasification, the content of H_2 and CO reaches 63.27–72.56%, while the content of H_2 and CO gets to 52.19–63.31% for biomass air gasification. The ratio of H_2/CO for biomass oxygen/steam gasification reaches 0.70–0.90, which is lower than that of biomass air gasification, 1.06–1.27. The experimental and comparison results prove that biomass oxygen/steam gasification in a Fluidized bed gasifier is an effective, relatively low energy consumption technology for hydrogen-rich gas production.

1. INTRODUCTION

Currently, most of the electrical or thermal energy consumed in the world is generated through the use of nonrenewable energetic sources that, in the future, will increase strongly their price due to their potential shortage in the market. On the other hand, there are the renewable energetic sources that can in the long term be used permanently without any exhaustion threat. This is the case of the biomass, which is currently being considered a promising energy source. The term biomass refers primarily to organic material originating from plants (including trees and agricultural crops).It is presently estimated to contribute about 10–14% of the world’s energy supply. A number of novel thermo-chemical and bio-chemical processes involving biomass are under development worldwide based on combustion, gasification, pyrolysis, and fermentation, among others. Many of these processes are based on fluidization. This project deals with experimentation and analysis of fluidized bed biomass gasification.

1.1 Gasification in brief

Gasification can be defined as a thermo chemical degradation of carbonaceous material under reducing atmosphere to a combustible gas with reasonable calorific value. In a gasifier, the carbonaceous material undergoes three processes. The pyrolysis process occurs as the carbonaceous particle heats up. Volatiles are released and char is produced. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions. Partial combustion occurs as the volatile products and some of the char reacts with oxygen to form CO2 and CO, which provides heat for the subsequent gasification reactions. The most relevant gasification reactions and their reaction Enthalpy are as follows,

$$C + H_2O \qquad CO + H_2 \qquad \Delta H_{298} = +131 \text{ kJ mol}^{-1} \qquad (1.1)$$

$$C + CO_2 \qquad 2CO \qquad \Delta H_{298} = +172 \text{ kJ mol}^{-1} \qquad (1.2)$$

$$C + 2H_2 \qquad CH_4 \qquad \Delta H_{298} = -75 \text{ kJ mol}^{-1} \qquad (1.3)$$

There is three oxidants to apply; air, steam and pure oxygen. The latter is affected with high economic and energy costs and is not considered useable in commercial applications. Since the use of pure oxygen is expensive, but offering considerable advantages as smaller downstream equipments, lowered compression energy, the use of oxygen enriched air combines the advantages in a less expensive medium.

The amount of air added the biomass is very important for the composition of the producer gas. More added air as oxidant reduces the efficiency, and increases the yield of gaseous products. The energy content of the products is a function of the equivalence ratio (ER). A ratio of one corresponds to stochiometric combustion. ER = 0 corresponds to pyrolysis, ER = 0.25 – 0.50 correspond to gasification and ER > 1 corresponds to combustion.

1.2 Fluidization

Fluidization is defined as the process by which solid particles are transformed into a fluid like state through suspension in a gas or liquid. Fluidized beds have been applied widely in processes involving gasification, pyrolysis and combustion of a wide range of particulate materials including biomass. Advantages of fluidization include high heat transfer, uniform and controllable temperatures, favorable gas–solid contacting and the ability to handle a wide variation in particulate properties.

2. Experimental section

2.1 Introduction

The experimental setup consists of the fluidized bed column 150 x 1000 mm in size. Fuel is fed through screw feeder and air is supplied through blower. In the down stream side, Cyclone separator, Tar separator (water scrubber), Diesel bath, Dryer and burner with sampling probes are placed. The entire bed is insulated with refractories and heater is placed at the base of the bed say 75mm height. The schematic of the experimental setup is shown in Fig 1 and Fig 2

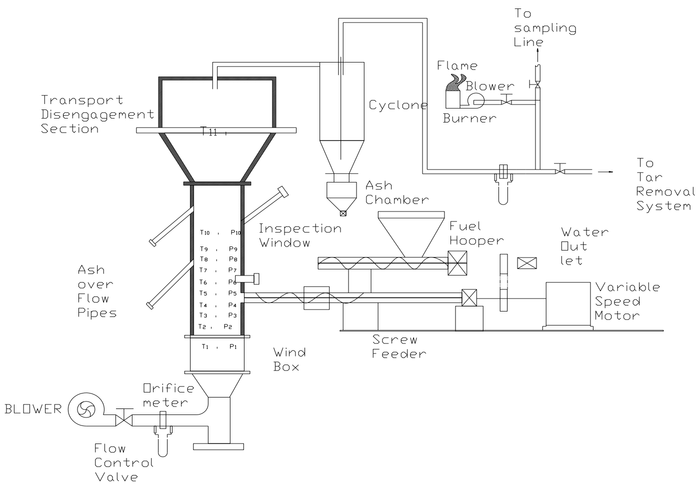

Figure 1. Schematic diagram of experimental setup

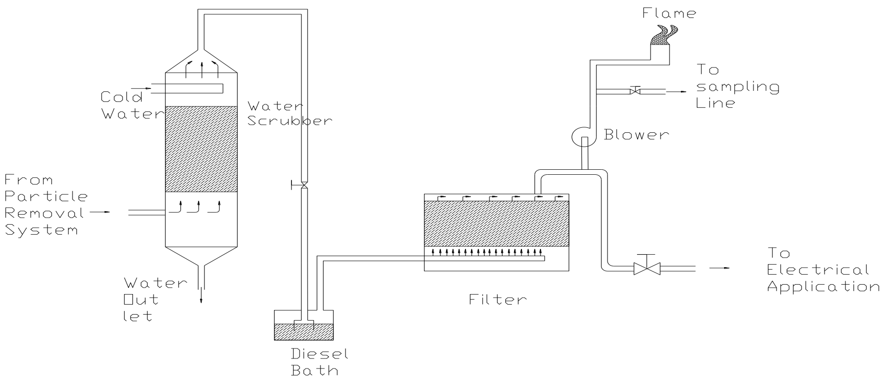

Figure 2. Schematic Diagram with downstream equipments of experimental setup

.2 Preliminary methods and materials required

Before experimentation certain preliminary measure like Calibration of screw feeder at different voltages for Saw dust and Groundnut shell, Calibration of Orifice air flow meter and particle sizing is done. Groundnut shell is grounded and separated to three distinct sizes say 1, 1.5 and 2.675 mm as shown in Fig 3 and Fig 4 shows the photographic view of the entire experimental setup.

Fig 3. PICTORIAL VIEW OF RICE HUSK

Fig 4. Three different particle sizes of Groundnut Shell

2.3 Instrumental details

The base fuel characteristics were measured in the SGS laboratory, Chennai. Producer gas composition was analyzed using Siemens make Online Gas Analyzers viz. Oxymat 61

(Estimates O_2 using paramagnetic principle), Ultramat 23 (Estimates CO, CO_2, and CH_4 using Non Dispersive Infrared multilayer technology) and Calomat 61 (Estimates H_2 using thermal conductivity principle). Chromel – Alumel (K type) thermocouples were used for measuring the temperature at different zones (T_1 to T_{10}). Water filled U tube manometer is used to measure the air flow and velocity through the Orifice air flow meter.

2.4 Experimental procedures

Experiments are initiated by heating the reactor with electrical heater till the reactor reaches about a temperature to desired level of 500 - 600°C. Biomass materials used in the present work are Groundnut shell and Saw dust. Inert material used here is sand with bulk density of 1473.44 kg/m^3 and average particle size 1100 µm. Air supplied should be more than twice the minimum velocity of fluidization. When the desired level of temperature is reached in the reactor fuel feeding from the screw feeder is started. The air flow and fuel feed rate are adjusted to get producer gas with a good combustion value. The same procedure is repeated at various reaction temperatures, Equivalence ratios and Particle sizes. Each time the compositions recorded in online gas analyzers are noted and Higher Heating Value (HHV) is calculated.

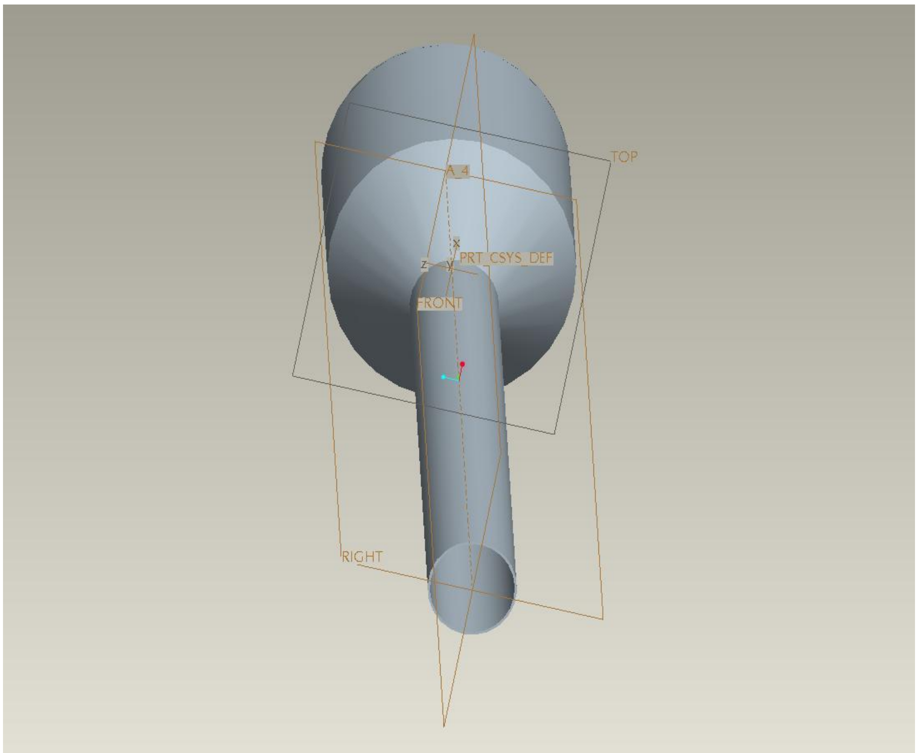

Fig 5. Pro-E View of furnace

3. RESULTS AND DISCUSSIONS

3.1 General

The main advantage of fluidized bed gasification is that it can able to handle variety of fuels, even low grade fuels to yield a combustible gas with reasonable calorific value. Using air as a gasifying agent the range of Calorific value obtained earlier with agro- residues is 2

– 4 MJ/m^3. Effect of temperature, Particle size and Equivalence ratio with Producer gas composition and its calorific value are studied in detail in this chapter.

3.2 Effect of temperature

In the present work the temperature of the reactor is varied from 650 °C – 800 °C and the corresponding variation in the producer gas composition at each particle size (1, 1.5 and 2.675 mm for Groundnut shell) and saw dust are noted. The results are plotted in Figure 6

The heat transfer rate is high in a fluidized bed reactor, the feed material is rapidly

heated from the ambient temperature to the operating temperature of the reactor. Thus, the

decomposition step proceeds very quickly. As a consequence, the composition and yield of the produced gas are likely to depend heavily on the secondary reactions. Since cracking and steam reforming reactions are endothermic, a higher operating temperature of the reactor would promote these reactions. Hence, the composition and yield of the gas produced would be strongly influenced by the gasification temperature. This is evidenced by the strong temperature dependence observed in the gas composition. At higher temperatures the concentration of hydrogen and carbon monoxide in the produced gas is found to be higher. The concentration of methane is found to follow a decreasing trend with increase in reaction temperature. Based on Le Chatelier's principle, it is comprehended that higher reaction temperatures favor the reactants in exothermic reactions while it favor products in endothermic reactions. Methane formed in the gasifier, at higher temperatures undergo endothermic reactions with already formed water vapour and get converted into CO, CO_2 and H_2. Hence the yield of CH_4 recedes at higher temperature and accordingly the yield of CO and H_2 increases with temperature.The molar concentration of methane is found to be lower, varies between 0.974 % to 3.96 % (v/v) when compared to other combustibles say hydrogen (varies between 6.18 to 12.78 %) and CO (varies between 10.14 to 18.54 %). Hence the total molar concentration of combustibles is found to be increasing with temperature increase.

This trend is found to be true for all particle sizes of Groundnut shell and Saw dust. Hence it is evident as the reaction temperature of gasification increases the Calorific value (H.H.V) also increases. The maximum gasification temperature reached in the present study is 800 °C which yields a gas with Heating Value of 4.133 MJ/m^3.

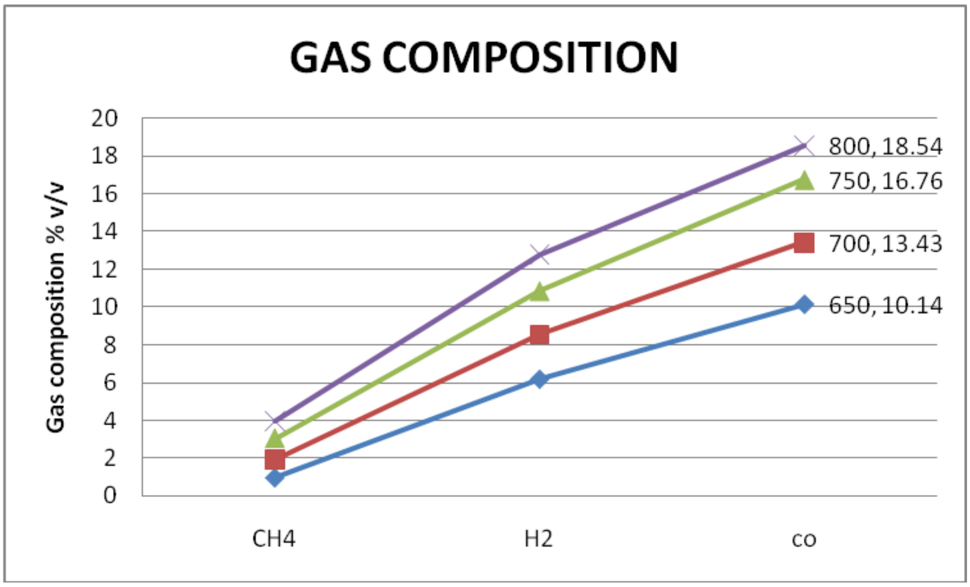

Figure 6. Variation of gas Composition w.r.t Temperature

3.2 Effect of equivalence ratio

Equivalence ratio (E.R) is the ratio of the actual A/F ratio to the stiochiometric A/F ratio. Discarding the fuel component, it could be also defined as the ratio of actual air supplied to the stiochiometric air requirement. The lower limit of E.R in an fluidized bed gasifier is fixed by considering the variety of factors like the minimum fluidization velocity above which the fluidized bed should operate, Fuel feed rate and reactor temperature etc., Similarly the upper limit of E.R is determined by gas quality, tar quantity, reactor temperature and material thermal potential etc., In the current study the lower limit of E.R is fixed as 0.35 below which no producer gas yield was obtained. When the E.R is increased to 0.4 the reaction prevails combustion and hence the calorific value reduces thereof. The variation of calorific value with E.R. 0.35 and 0.4. With ground nut shell of size 1 mm the HHV obtained at E.R of 0.35 and temperature 800 °C is 4.13 MJ/m^3.

4. CONCLUSION

The phenomenon of fluidization pertaining to gasification is complex and difficult to ascertain. The synopsis presented, details the methodology to gasify biomass in a fluidized bed. The results conclude that Groundnut shell could be gasified without any major hassles in fluidized bed gasification systems. The combustion value of producer gas from groundnut shell at all particle sizes (1 mm, 1.5 mm and 2.675 mm) is higher than Saw dust at all operating conditions and hence Groundnut shell proves to be a better fuel than Saw dust. The calorific value of groundnut shell ranges from 2.4545 MJ/m^3 to 4.133 MJ/m^3, which seems to be reasonable with air as a gasifying agent. Experimental runs show the strong dependence of combustible gas composition with reaction temperature. As the temperature increases the calorific value increases and attains the maximum value of 4.133 MJ/m^3 at temperature of 800 °C.

As the particle size decreases the calorific value shows an increasing trend. It reaches a minimum value of 2.873 MJ/m^3 at 650°C for a maximum particle size of 2.675 mm and gradually increases with decrease in particle size and temperature increase. Equivalence ratio of 0.35 is found to be the best operating point from experimental investigations. As overall the optimum conditions for gasifying groundnut could be summarized as below, the optimum Values of temperature of 800°C and equivalence ratio with particle size 1mm.The composition of combustible gas is 32.5% and the calorific value is 4.133MJ/m^3.

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